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Failure Analysis on Alloy 600 Components in Korean Nuclear Power Plants

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1. Introduction

Primary water stress corrosion cracking(PWSCC) of alloy 600 in a PWR has been reported in the control rod drive mechanism (CRDM)[1], In original PWRs, the SCC was not considered appropriately. Beginning in the mid seventies the world's PWR plants suffered from a sequence of SCC events mostly confined to S/G tubes, initially ODSCC then PWSCC. In forged alloy 600 materials, PWSCC was first reported in the Bugey 3 vessel head penetration in September1991. All reactor vessel heads(RVH) with alloy 600 penetrations (54 VH out of 58) were replaced in France. Other PWRs experienced cracking attributed to PWSCC of major primary side welds made from Alloy 182 at the end of the year 2000. The three events concerned dissimilar metal butt welds between the main austenitic stainless steel primary circuit piping and the outlet pressure vessel nozzles of Ringhals 4 and V. C. Summer and some J-groove welds of the CRDM of the RVH at Oconee 1. [2]

In addition to the RVH, PWSCC of Alloy 182/82 has been reported at Bottom Mounted Instrumentation (BMI) nozzle J-welds, Steam Generator (SG) drain J-welds drain nozzle and SG tube sheet cladding [3]. As of the year 2006, 344 PWSCC incidents of Alloy 600/82/182 were reported in RVH, SG, Pressurizer, and other primary side pipings.

With regard to Alloy 600TT SG tubes which are known to be much more resistant to SCC than Alloy 600MA tubes, US plants (Seabrook and Vogtle 1) experienced ODSCC.

The objective of the present work is to review the PWSCC events and some countermeasures to manage the degradation. Moreover this work deals with the ODSCC occurred in Alloy 600TT SG tubes

2. PWSCC in Drain nozzle of SG

2.1 Carbide morphology

Solution treatment temperature of 980 ^{o}C is considered to be a little too low to dissolve all the carbides in the nozzle material with 0.04% carbon, as illustrated in Fig. 1. Grain boundary carbides were relatively well developed in the material as shown in Fig. 2. A Cr-depletion was not observed near the grain boundaries. From the observed SCC resistant microstructure[1,2] it was considered that the material itself was not the cause of the cracking. Rather, the weld residual stress could be the main cause of the PWSCC of the alloy 600 nozzle.

2.2 Fracture surface analysis

A typical morphology of the cracks is shown in Fig. 3. The cracks were developed from the inside of the pipe wall and propagated outward. Intergranular nature of the cracks suggests that the nozzle was attacked by a PWSCC.

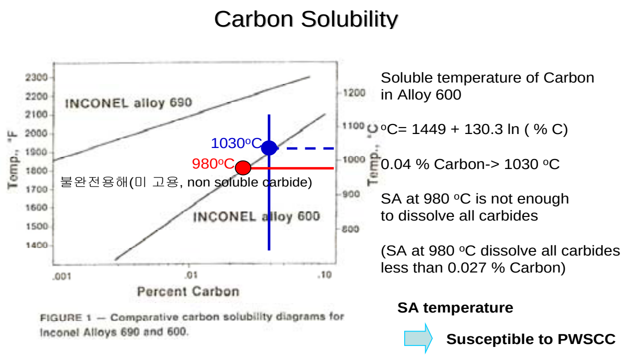

Fig. 1 Annealing temperature and carbon contents in alloy 600 and 690

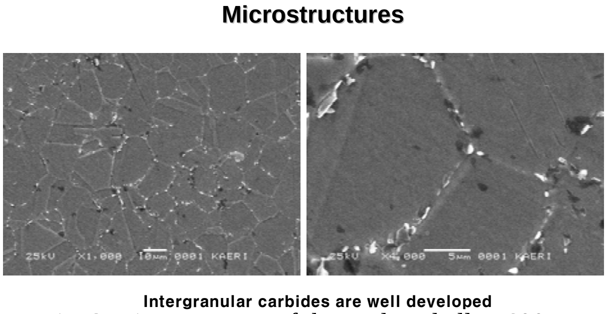

Fig. 2 Microstructure of the analyzed alloy 600 nozzle

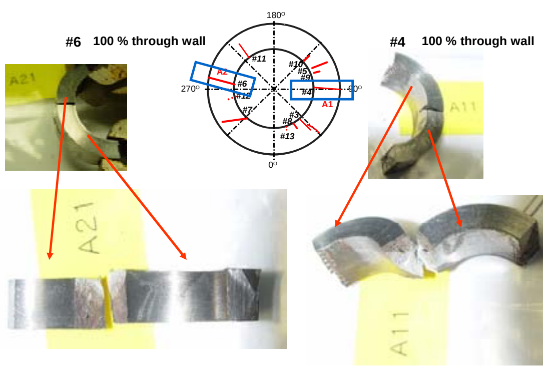

Fig. 3 Typical crack morphology of the drain nozzle

It was found that two cracks out of twelve had fully penetrated the pipe wall, and the maximum length was 7.2 mm. Because the upper part of the nozzle was ground out during the pulling process, the longest crack length could be longer than the measured value by the destructive examination.

3. PWSCC in RVH Vent Pipe

3.1 Fracture surface morphology

The fracture surface of the degraded RVH vent pipe is shown in Fig. 4. The crack was initiated on the inner diameter (ID) and propagated to the outer diameter (OD). The crack propagated along the grain boundaries, therefore the cracking morphology was purely intergranular SCC. All these facts imply that the cracking was occurred by PWSCC.

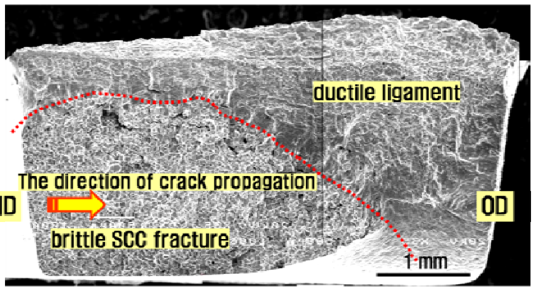

Fig. 4 SEM micrograph of the fracture surface of RVH vent pipe.

3.2 Microstructure and stress analyses

The intergranular carbide precipitation and the resultant Cr depletion around the grain boundary are critical in the SCC phenomena. For high resistance to PWSCC, intergranular Cr carbides should precipitate on the grain boundary in a nearly continuous form [3]. The intergranular Cr morphology and the Cr depletion around the grain boundary in the RVH vent pipe are shown in Fig. 5. It can be expected from the figure that the PWSCC resistance of the vent pipe could be low.

From the result of the stress analysis applied to the vent pipe (not shown here), it can be concluded that the hoop stress is high enough to initiate and propagate easily an axial crack in the vent pipe, which agrees well with the field experience.

4. ODSCC in Steam Generator Tube

Alloy 600TT SG tubes were pulled and examined destructively. From the examination of the fracture surface, it was found that the occurrence of intergranular stress corrosion cracking (IGSCC) was observed as shown in Fig. 6.

The causes of IGSCC were analyzed through the microstrucural investigation, mechanical, corrosion property, oxide investigation and microscopic observation.

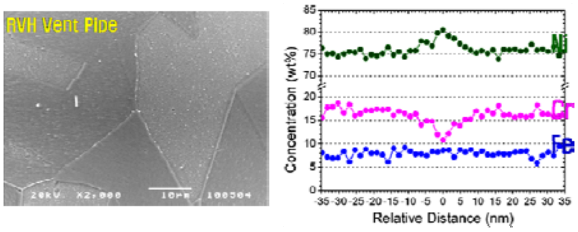

Fig. 5 Intergranular Cr carbide precipitation and the resultant Cr depletion in the RVH vent pipe.

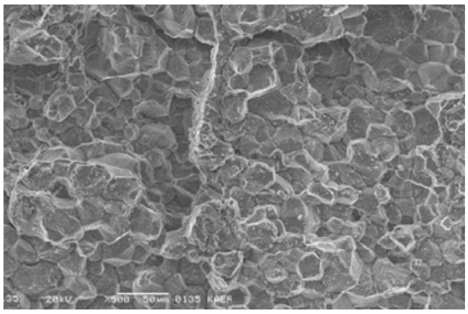

Fig. 6 SEM image of fracture surface for Alloy 600 TT tube.

5. Conclusions

(1) PWSCC in Drain nozzle of SG

- Grain boundary carbides were well developed in the material, therefore, the material itself was not the cause of the cracking.
- Residual stress due to the welding process could be a main cause of the PWSCC of the alloy 600 nozzle.

(2) PWSCC in RVH Vent Pipe

- Cracking was occurred in the RVH vent pipe because of the PWSCC susceptible material and the high residual hoop stress due to welding.

(3) ODSCC in SG tubes

- Chromium carbides were not well developed along the grain boundary of Alloy 600 TT material and the small average grain size of 15~20μm was observed. The sludge was found easily around the crack where Pb of several percent was observed. Residual stress as well as the stress caused by ID/OD temperature difference and pressure during the operation was introduced. By the combination of material, environment and stress, IGSCC occurred in Alloy 600TT SG tubes.

REFERENCES

[1]EPRI TR-1303696, “PWSCC of Alloy 600 Materials in PWR Primary System Penetrations”, July 1994
[2] S. M. Bruemmer, Corrosion, 44(11), 782 (1988)
[3] EPRI TR 103898-PWSCC alloy 600, 1994